High Pressure Safety Injection Reliability Study

1 HPI SYSTEM FAULT TREE MODELS

The fault tree models for the six design classes illustrate the logic used for generating the 72 plant-specific HPI unreliability models (injection phase only). Plant-specific models were generated since there are some HPI design and operation differences within a design class.

1.1 HPI Unreliability

Estimates of HPI unreliability for the actual missions experienced are calculated. These unreliability estimates are based on the operational events that result from a SI actuation signal (manual or automatic) and a demand for high-pressure safety injection. These events for HPI operation can range from a few minutes to a few hours.

1.1.1 HPI System Modeling Assumptions

The six HPI design class models were developed to categorize the levels of cold leg and pump train redundancy and diversity (high-head and intermediate-head) across the industry. The steam generator criterion was used for a matter of convenience instead of the number of cold legs. The number of cold legs is correlated to the number of steam generators. The steam generator criterion reduced the number of possible groupings of HPI design. The unreliability of the HPI system was calculated using the plant-specific fault tree models. The models were constructed to reflect the failure modes identified in the unplanned demand data and the levels of redundancy and diversity of the HPI piping segments. In most cases, the fault tree models used the small LOCA success criteria stated in the PRA/IPEs (refer to Table 1 of the System Description for the success criteria). However, the success criterion for several plants was modified to eliminate the non-safety class pump trains modeled in some PRA/IPEs. Failures are not reportable for these types of pump trains. Therefore, estimates for these types of non-safety components were not calculated. Further, the success logic was modified to account for the in-line spare pump that required operator actions to place the spare HPI pump in service (e.g. reconnecting the spare pump to an electrical bus).

The failure of the RWST suction path was modeled and it was the dominant failure for HPI Design Class 6 plants although there were no failures in the unplanned demand data extracted from the 1987–1997 experience. The failure mode associated with this segment was included as the dominant failure in the quantification because of the following reasons:

- Although no complete failure of this segment was observed in the unplanned demand data for this segment, partial failures of the RWST suction path identified in the 1987–1997 experience tends to support this failure mode as being credible. Even though this failure dominates Design Class 6, the failure probability estimated for this segment is low, about 5E-05.

- Design Class 6 uses redundancy (four or five pump trains and eight injection paths) and diversity (high-head and intermediate-head pumps) in the HPI systems. Because of these features, it is reasonable for the RWST suction segment (this is the shared between high and intermediate subsystems) to have a major effect on HPI unreliability.

Estimates of HPI unreliability were calculated using the 1987–1997 experience using only the unplanned demand data. These data were statistically analyzed to develop failure probabilities. The following failure modes are based on the 1987–1997 experience (based on the unplanned demand data):

- Maintenance-out-of-service—Pump, driver, valves, and associated piping (MOOS)
- Failure to Operate: Train Actuation—High-Pressure Safety Injection (SI) actuation channels (FTO-ACT)
- Failure to Start—Pump, driver, valves and associated piping (FTS)
- Failure to Run—Pump, driver, valves and associated piping (FTR)
- Failure to Operate—Injection header valves (HPI isolation, etc.) and associated piping faults (FTO-INJ)
- Failure to Operate—Loop (cold leg) injection paths and associated piping faults (FTO-LOOP-INJ).
- Failure to Operate—RWST suction path and associated piping faults (FTO-RWST-SUCT).

The following conditions were assumed for the purposes of quantifying the operational mission fault tree:

- A demand (SI actuation), whether actual or inadvertent, to provide high-pressure safety injection to a cold leg is received by the HPI system.
- The only mode of HPI modeled is the injection phase. Alternate suction sources were not modeled. Further, the long-term recirculation mode of HPI is not modeled.

1.2 HPI Design Class Fault Trees

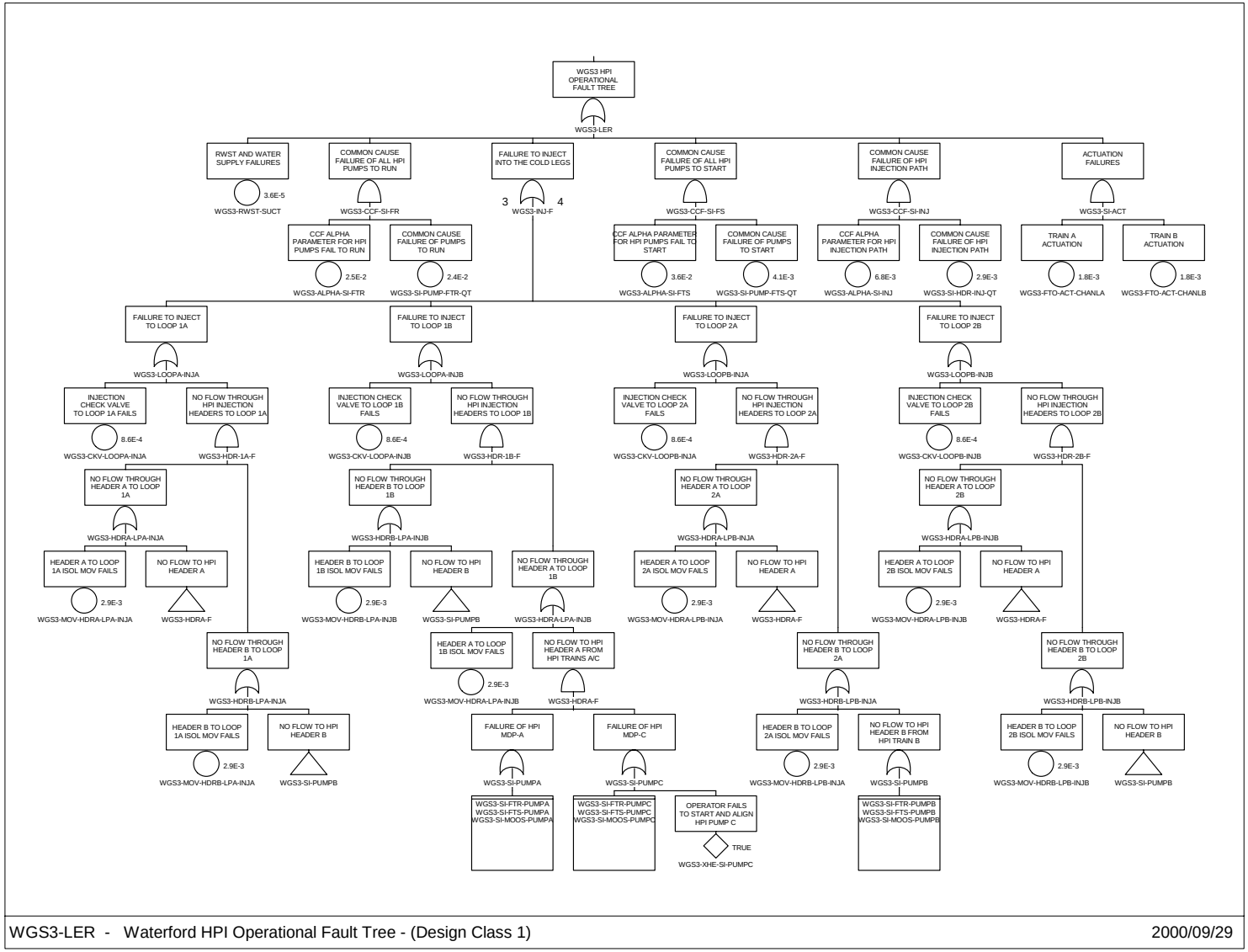

Figure 1. HPI Design Class 1.

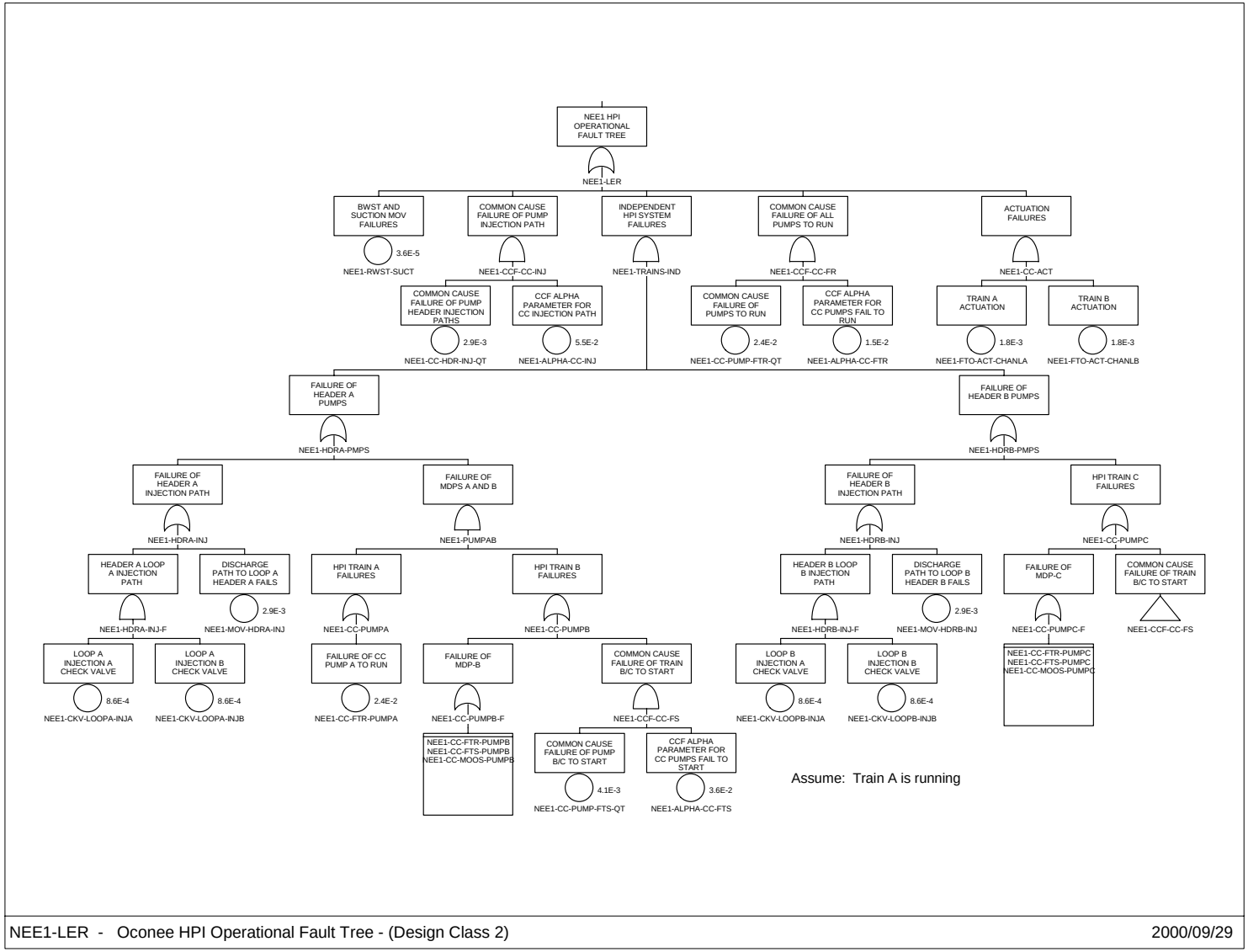

Figure 2. HPI Design Class 2.

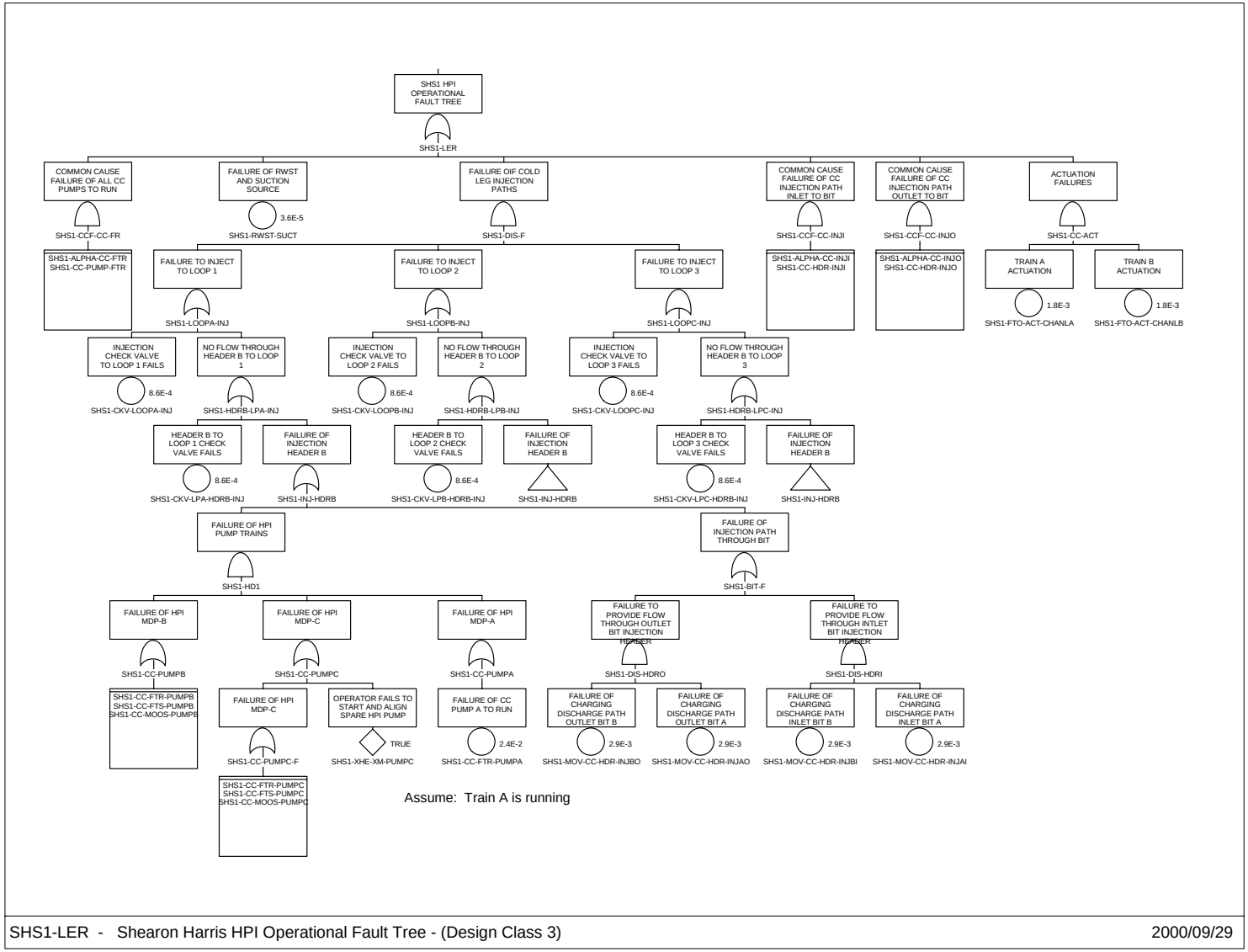

Figure 3. HPI Design Class 3.

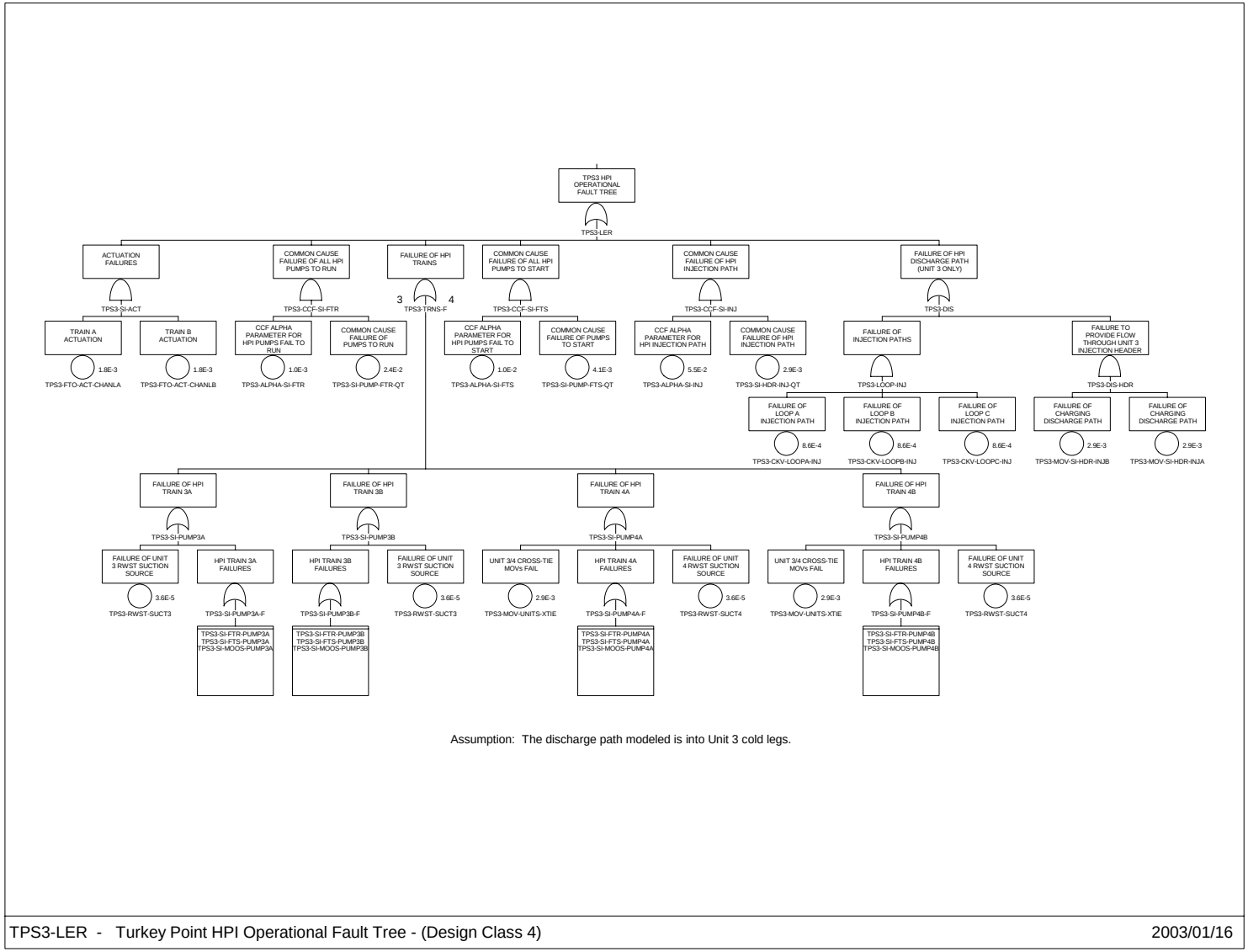

Figure 4. HPI Design Class 4.

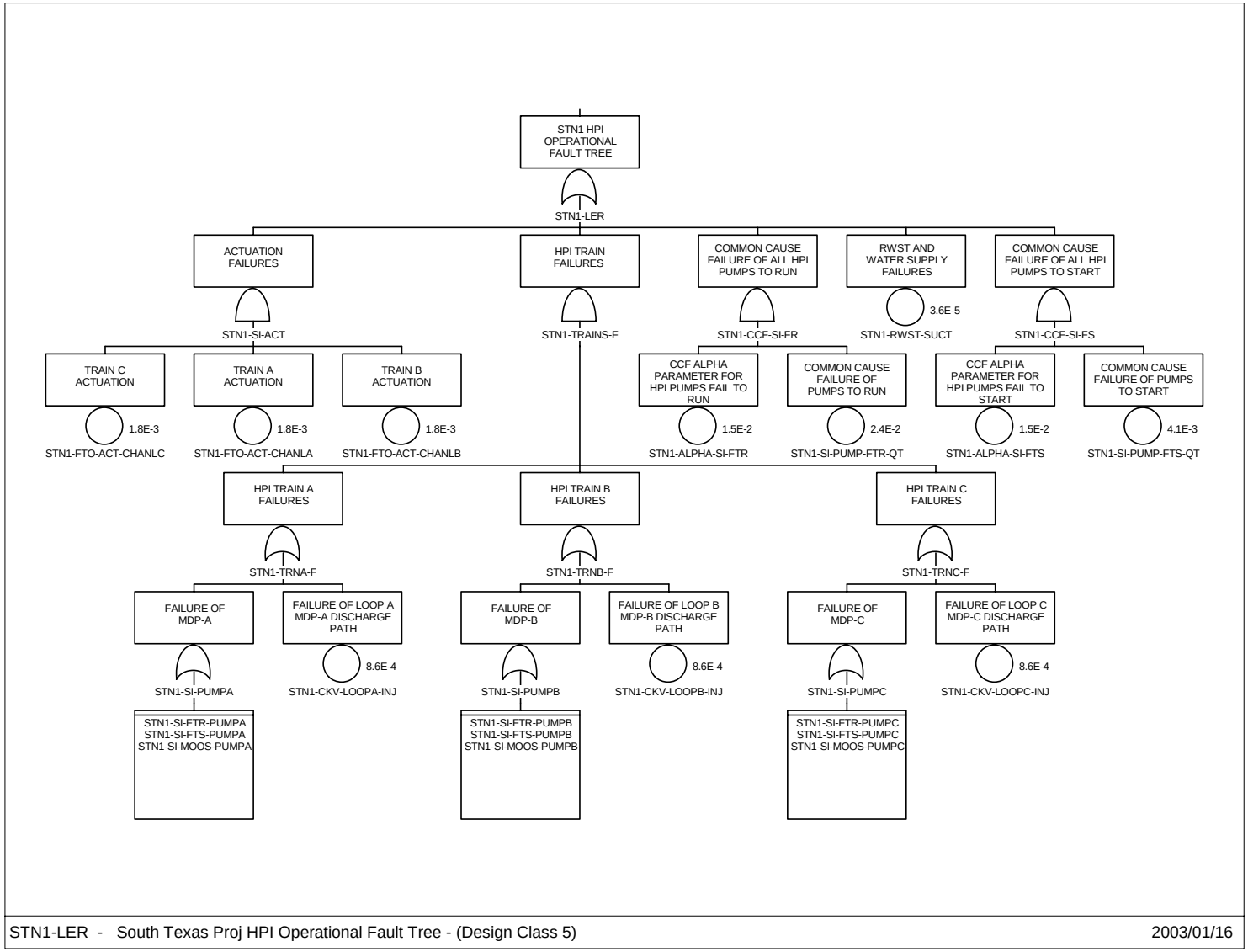

Figure 5. HPI Design Class 5.

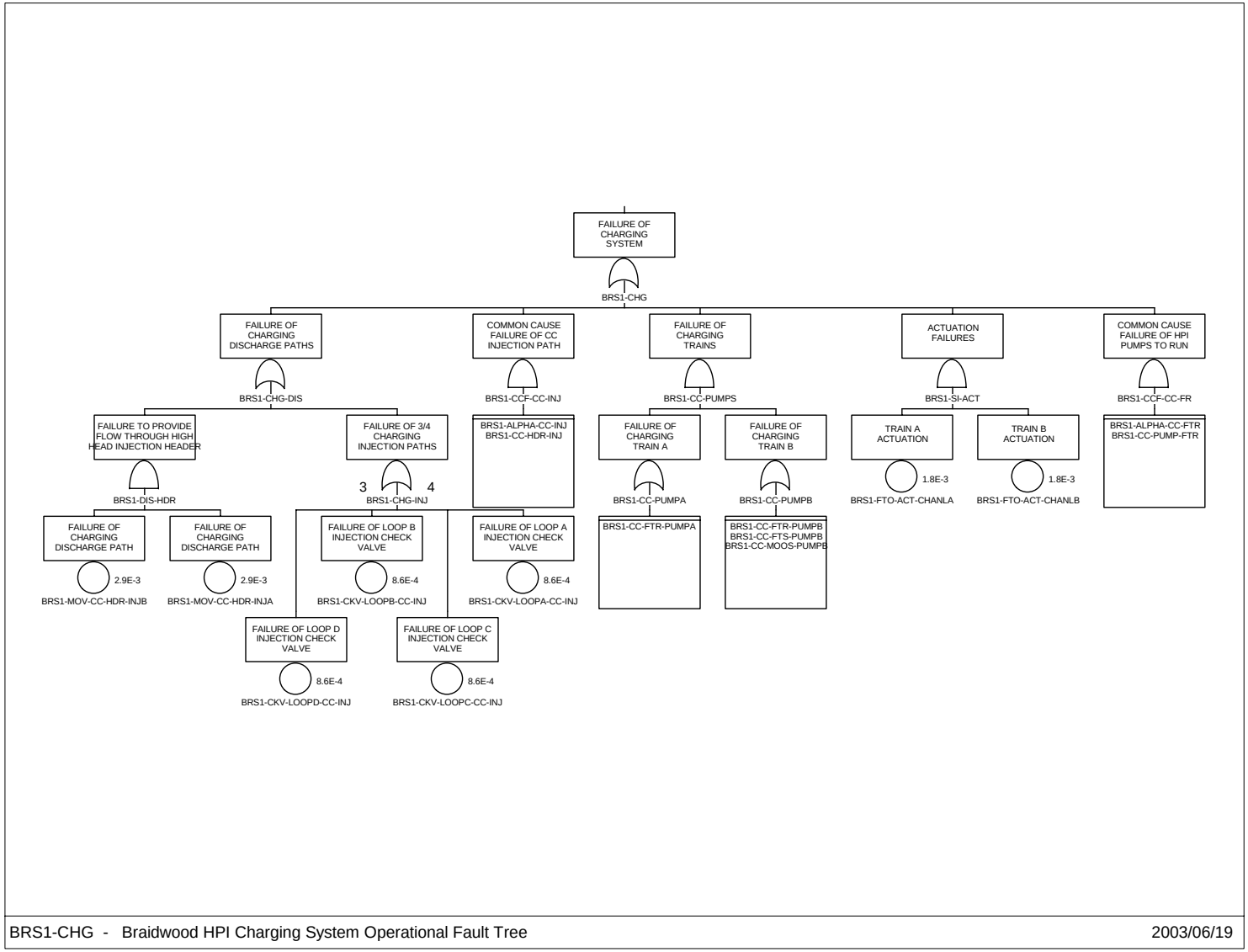

Figure 6. HPI Design Class 6.